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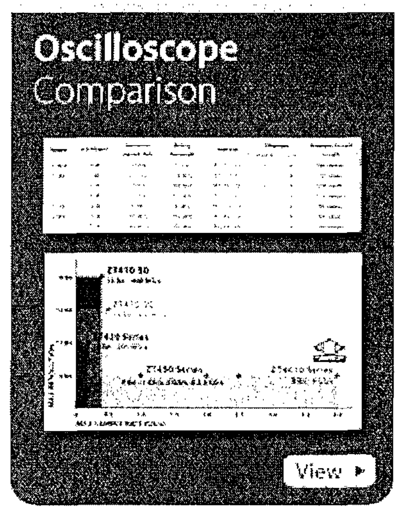
Oscilloscope Overview



Oscilloscope Measurement Fundamentals: Frequency Domain Measurements (Part 3 of 3)

A Three Part Article Series:
Oscilloscope Measurement Fundamentals

1 Vertical-Axis Measurements
2 Horizontal-Axis Measurements
3 Frequency Domain Measurements

This is part three in a three part series in which we will examine oscilloscope measurements such as the ones available in hardware within the ZTEC family of modular oscilloscopes.
Many oscilloscope users take advantage of only a small fraction of the powerful features available to them. In addition, selecting the right measurement from a catalog of possibilities and accurately interpreting the results can lead to confusion and mistakes. This series of articles is intended to help users understand oscilloscope measurements more completely in order to avoid common pitfalls.

Digital storage oscilloscopes vary greatly among vendors in terms of form factor (stand-alone, PXI, VXI, PCI, etc), resolution (8-bit, 12-bit, 16-bit, etc), acquisition rates (1 MS/sec, 1 GS/sec, 40 GS/sec, etc), functionality (advanced triggering, deep memory, self-calibration, etc.), and more. One aspect that separates true oscilloscopes from most PC-based, modular digitizers is the ability to make measurements in hardware on an onboard processor. The available measurements also differ from one oscilloscope to another, although this paper will cover a large segment of them. In addition, the algorithms used to complete the measurements may differ slightly among vendors. This paper will focus on the measurements and algorithms used in ZTEC modular oscilloscopes, but most of these concepts are universal.

Oscilloscope measurements can be sorted into the following three categories:

- Vertical-Axis
- Horizontal-Axis
- Frequency Domain

Part three of the series will focus on frequency domain measurements.

Part 3 of 3: Frequency Domain Measurements

Frequency domain measurements involve translating a time-domain waveform with a fast *Fourier transform* (FFT), and then measuring the noise and distortion characteristics in the frequency domain. Frequency domain measurements provide magnitude and phase characteristics versus frequency.

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Frequency Resolution and Accuracy

Using the FFT to quickly transform a signal into its frequency components is powerful, because it reveals signal characteristics that can't be seen in the time-domain. The FFT used within ZTEC oscilloscopes returns complex IQ data which is then converted to magnitude and phase data. Figure 1 shows the result of calculating the FFT of a signal and a few of the measurements.

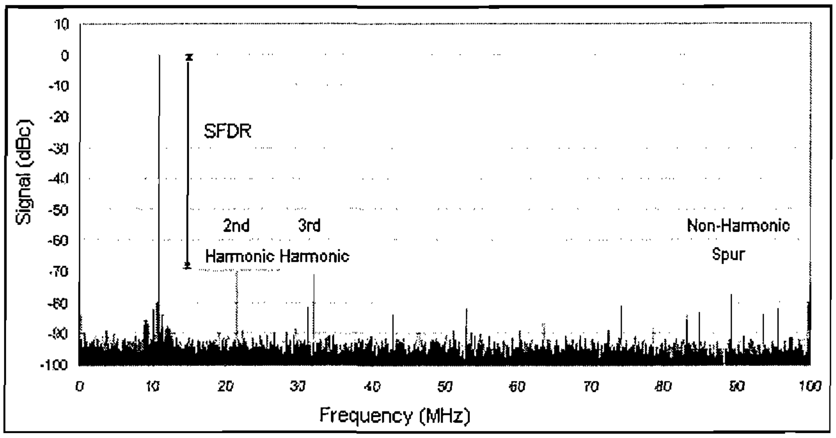

Figure 1: Frequency Domain Measurements

ZTEC oscilloscopes provide four FFT windows that can be applied as well. Windows are used to increase the spectral resolution in the frequency domain. The Rectangular Window provides the best frequency and worst magnitude resolution. It is almost the same as no window. The Blackman-Harris Window provides the best magnitude and worst frequency resolution. The Hamming Window provides better frequency and worse magnitude resolution than the Rectangular Window. It provides slightly better frequency resolution than the Hanning Window. The Hanning Window provides better frequency and worse magnitude resolution than the Rectangular Window.

Like some of the vertical- and horizontal-axis measurements discussed previously, the accuracy of the FFT can be improved by analyzing longer waveforms. Due to the nature of the calculations, the resolution is limited to half of the resolution of the onboard processor. In the case of the ZTEC ZT4611 oscilloscope, which uses a 64-bit processor, the accuracy would be limited to 32 bits of resolution. The FFT algorithm is binary in nature, so for the best performance it is wise to select a waveform size that is equal to 2^N.

Frequency Domain Measurements

Once a signal has been converted to the frequency-domain, five valuable measurements can be performed as explained in the following paragraphs. All of these measurements assume that the input signal is a perfect single-frequency sine wave and that all other frequency components are assumed to be harmonics or noise. All except the ENOB (bits) are expressed in decibels relative to carrier (dBc). THD is the only negative value.

The *Signal-to-Noise Ratio* (SNR) is the ratio of the RMS amplitude of the fundamental frequency to the RMS amplitude of all non-harmonic noise sources. SNR does not include the first nine harmonics as noise. In Figure 1, the SNR would be computed by dividing the magnitude of the fundamental by the sum of the magnitudes of all of the other frequency components, excluding the 2nd through the 10th harmonics. SNR is commonly used when only the narrow-band around the fundamental frequency is of concern and the harmonics will not have an effect on the system under test.

The *Total Harmonic Distortion* (THD) is the ratio of the RMS amplitude of the sum of the first nine harmonics to the RMS amplitude of the fundamental. In Figure 1, this would be calculated by summing the magnitudes of the 2nd through the 10th harmonics and then dividing that by the fundamental magnitude. THD is a concern when using active components such as amplifiers and mixers where the harmonics need to be minimized to reduce distortion.

The *Spurious-Free Dynamic Range* (SFDR) is the ratio of the RMS amplitude of the fundamental to the

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RMS amplitude of the largest spurious signal. This spurious signal can be a harmonic or noise frequency component. In Figure 1, the SFDR would be computed by dividing the magnitude of the fundamental by the magnitude of the 2nd harmonic, since it is the largest spurious signal. SFDR is used when there is a dominant spurious signal in relation to the other noise and distortion components.

The *Signal-to-Noise and Distortion* (SINAD) is the ratio of the RMS amplitude of the fundamental to the RMS amplitude of the sum of all noise and distortion sources. This is equivalent to the sum of the SNR and THD. In Figure 1, this would be calculated by dividing the magnitude of the fundamental by the sum of the magnitudes of all of the other frequency components, including harmonics and noise. SINAD is used in broad-band applications where all harmonics and noise will affect the signal.

The *Effective Number of Bits* (ENOB) is another way of expressing SINAD. It provides a measure of the input signal dynamic range as if the signal were converted using an ideal ADC. For instance, the ENOB of an 8-bit oscilloscope is often somewhere in the 6-7 bit range due to the noise and distortion affecting the instrument. The ENOB is calculated using the following equation:

$$\text{ENOB} = \frac{\text{SINAD} - 1.763}{6.02}$$

High-Speed ADC Test Example

The specifications and test procedures of a high-speed Analog to Digital Converters (ADCs) are generally expressed in the frequency domain. The frequency measurements on a ZTEC oscilloscope can be used to mimic a more expensive spectrum analyzer to complete these tests. One test that is often used is a two-tone or multi-tone distortion test. This is completed because intermodulation distortion can occur when the ADC samples a signal composed of more than one sine wave. Figure 2 shows the FFT of an acquired ADC data record undergoing a two-tone test. Once the FFT is created, measurements such as THD and SINAD can be used to characterize the performance of the ADC.

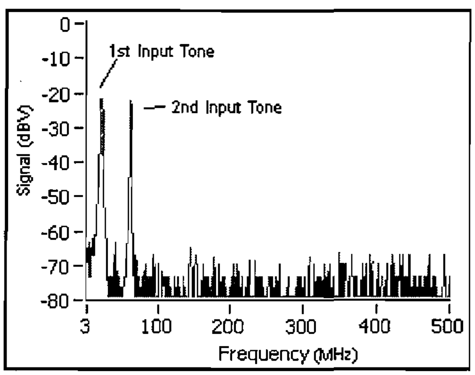

Figure 2: FFT of Two-Tone Distortion Test

This concludes the third and final installment of "The Fundamentals of Oscilloscope Measurements". Hopefully, these articles have provided our readers with a little deeper understanding of the waveform measurements available from an oscilloscope. This understanding can help users leverage the power of oscilloscopes more effectively and avoid potential pitfalls.

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